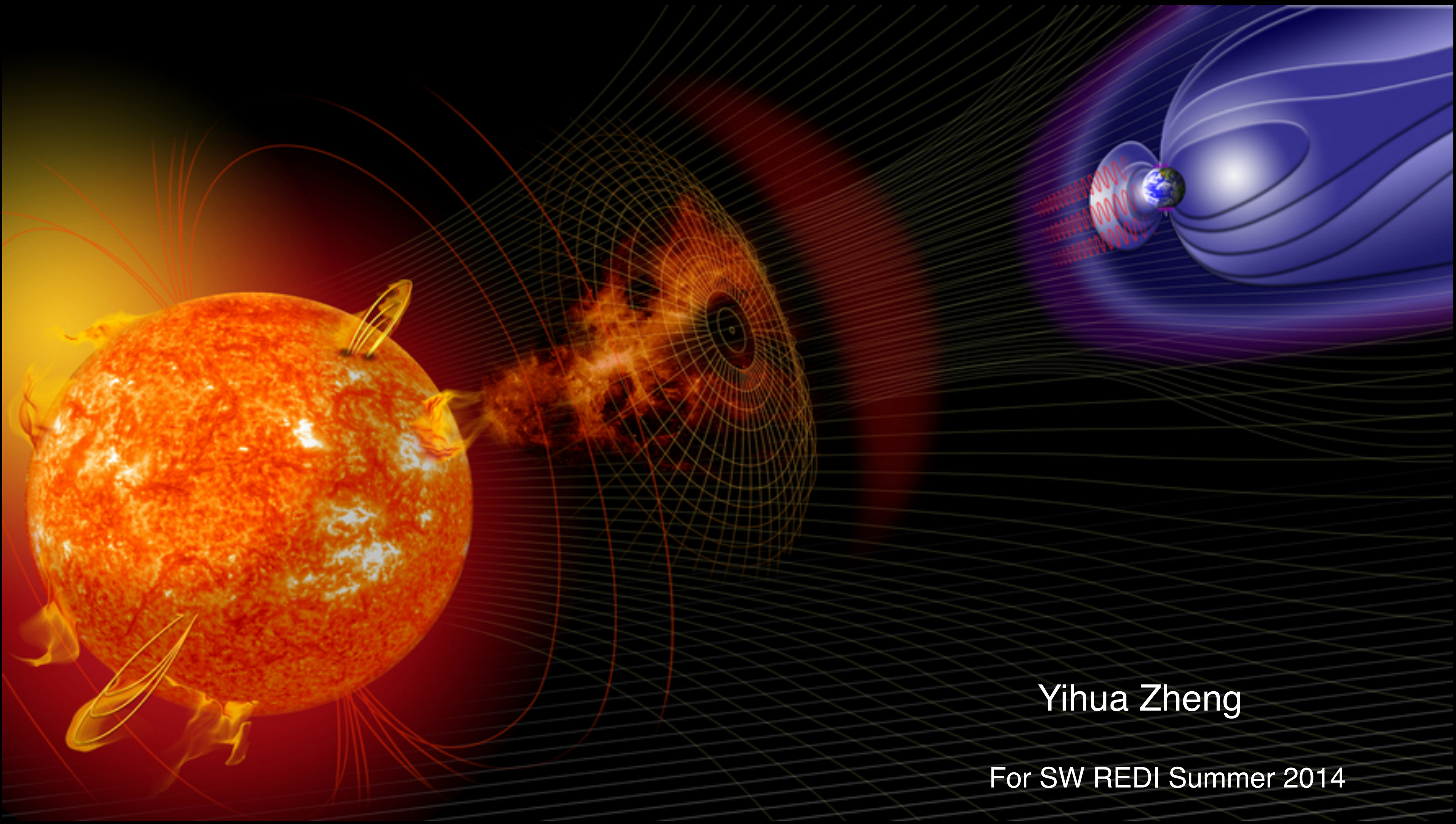
Introduction of Space Weather



Yihua Zheng

For SW REDI Summer 2014

- Space is NOT empty!
- There is weather in space - space weather
- Space is full of plasma - 4th state of matter (gas, liquid, solid)
    - plasma: important role in our plasma universe
    - plasma: important for space weather

Plasma

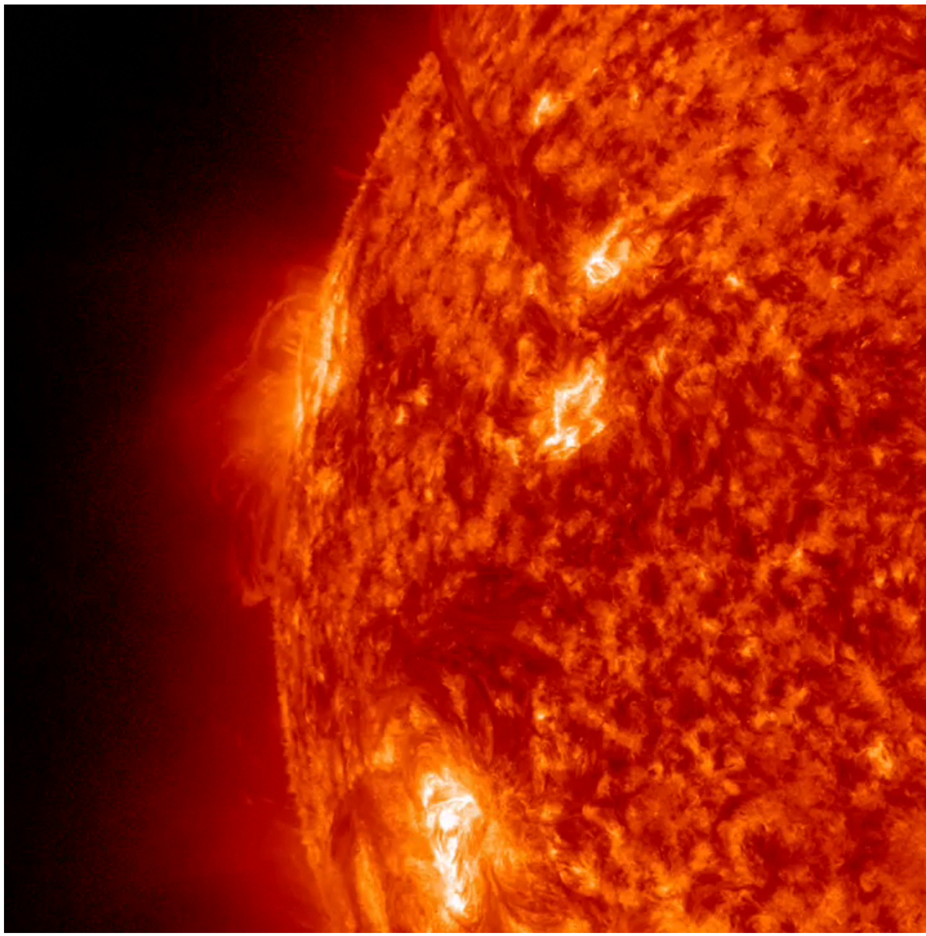
electrified gas with atoms dissociated into positive ions and negative electrons

- 99% of the matter in universe is in the plasma state
  - Stellar interiors and atmospheres, gaseous nebulae, interstellar material are plasmas, Earth's ionosphere and above
- We live in the 1% of the universe in which plasmas do not occur naturally

A plasma is a quasineutral gas of charged particles which exhibits collective behavior

Prominence Eruption

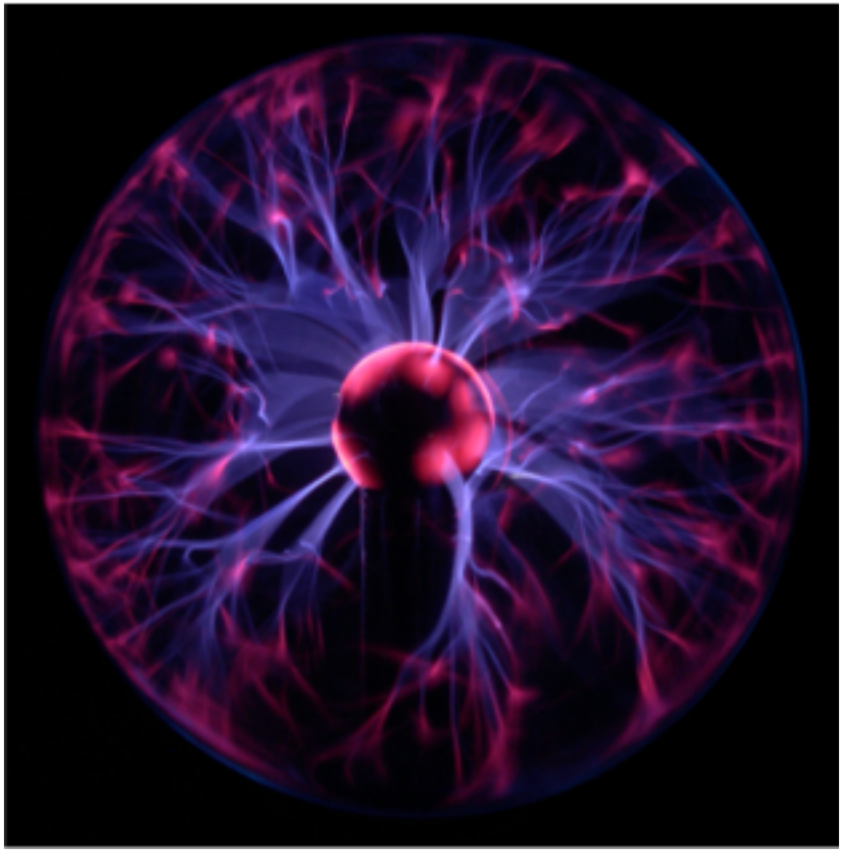
Aurora



Aurora: plasma interaction with molecules/atoms in the atmosphere

Plasma

A **plasma display** panel (PDP) is a type of flat panel display common to large TV displays 30 inches (76 cm) or larger. They are called "plasma" displays because the technology utilizes small cells containing electrically charged ionized gases, or what are in essence chambers more commonly known as fluorescent lamps.



Manmade: plasma TV, lamp, fluorescent tube, neon sign

Space Weather

- NSWP: Space weather refers to the variable conditions on the Sun and in the space environment that can influence the performance and reliability of spaceborne and groundbased technological systems, as well as endanger life or health.

- ESA: “Space weather refers to the environmental conditions in Earth's magnetosphere, ionosphere and thermosphere due to the Sun and the solar wind that can influence the functioning and reliability of spaceborne and ground-based systems and services or endanger property or human health”.

- ESA: Space weather deals with phenomena involving ambient plasma, magnetic fields, radiation, particle flows in space and how these phenomena may influence man made systems. In addition to the Sun, non-solar sources such as galactic cosmic rays can be considered as space weather since they alter space environment conditions near the Earth.

Main Causes of Space Weather

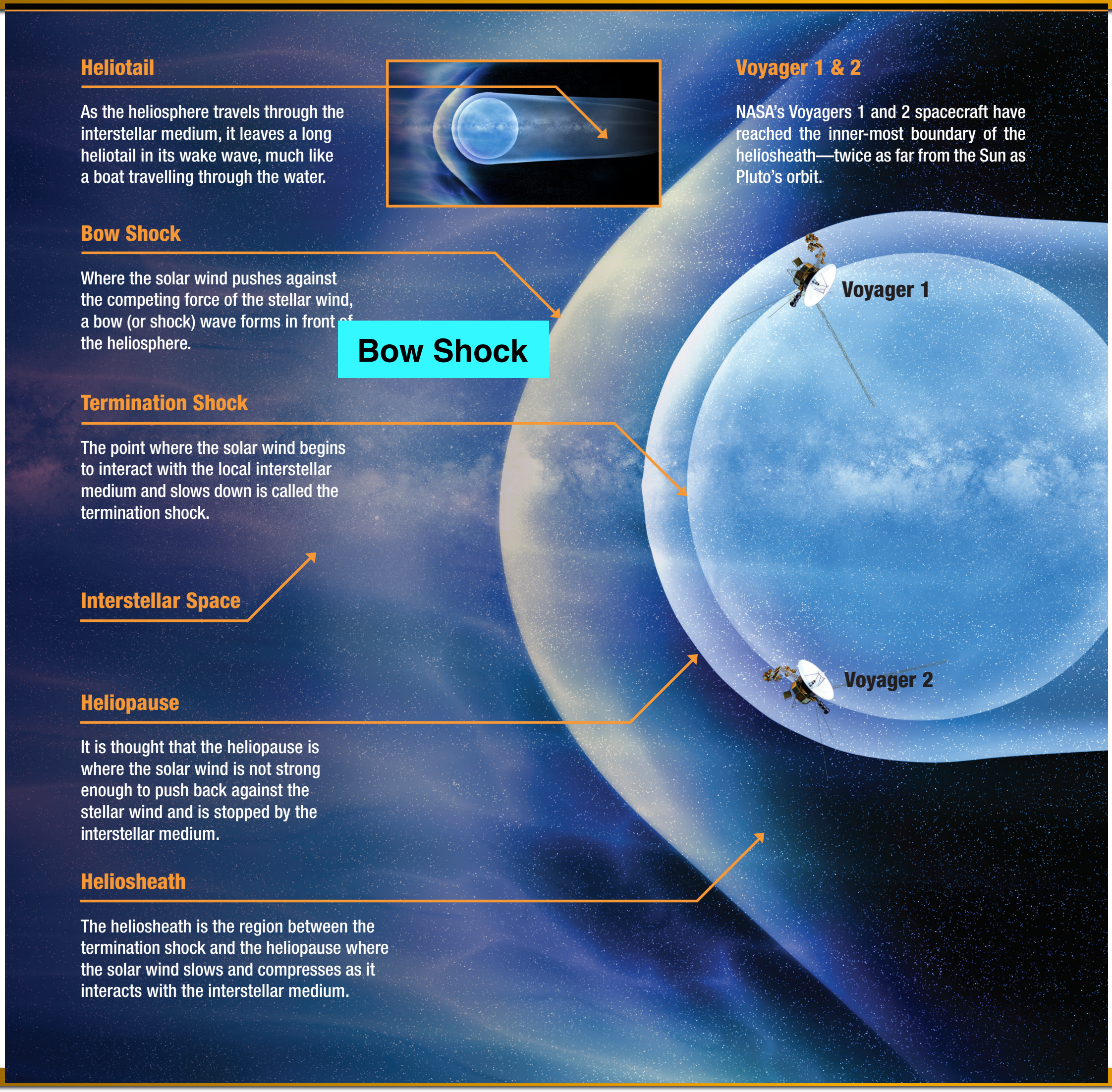
- **Solar Activity and the Solar Wind (Flare, CME, SEP, coronal hole high speed streams)**
  - *driver*
- **Galactic Cosmic Rays -** *driver*
- **Meteoroids and Space Debris -** *driver*

The sun is the main driver of space weather

Main Causes of Space Weather

- Solar Activity and the Solar Wind - *driver*
- Solar energetic particles and their entry into the magnetosphere - *driver/in-situ response*
- Galactic Cosmic Rays - *driver*
- Meteoroids and Space Debris - *driver*
- The Earth's Magnetosphere: Geomagnetic Storms (and Substorms) - *driver & internal response*
- Radiation Belts - *driver & internal response*

Physical Domains - Heliosphere



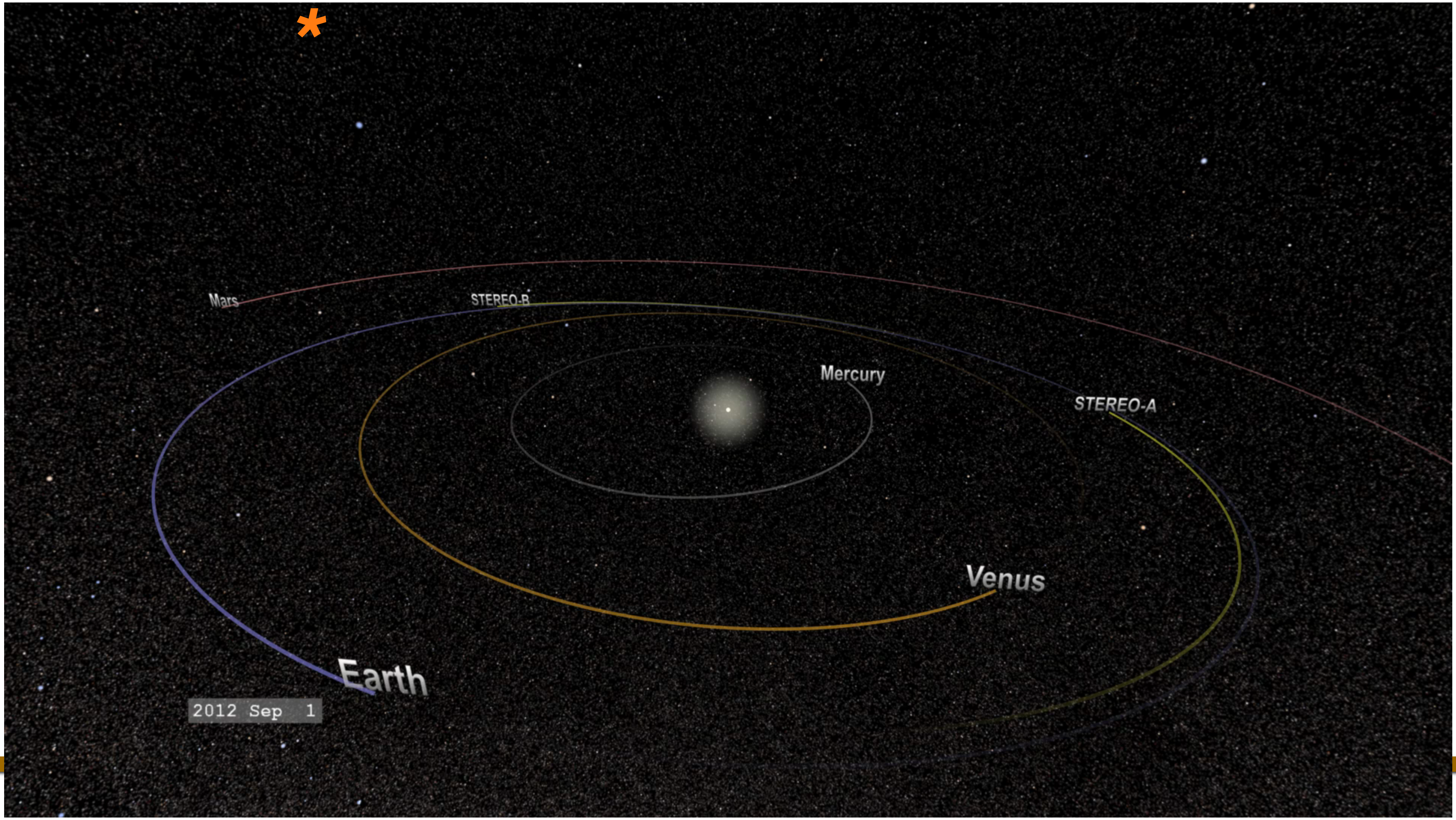
Heliosphere: the outer atmosphere of the sun
Marks the edge of the Sun's magnetic influence in space

the solar wind carves out a bubble-like atmosphere that shields our solar system from the majority of galactic cosmic rays

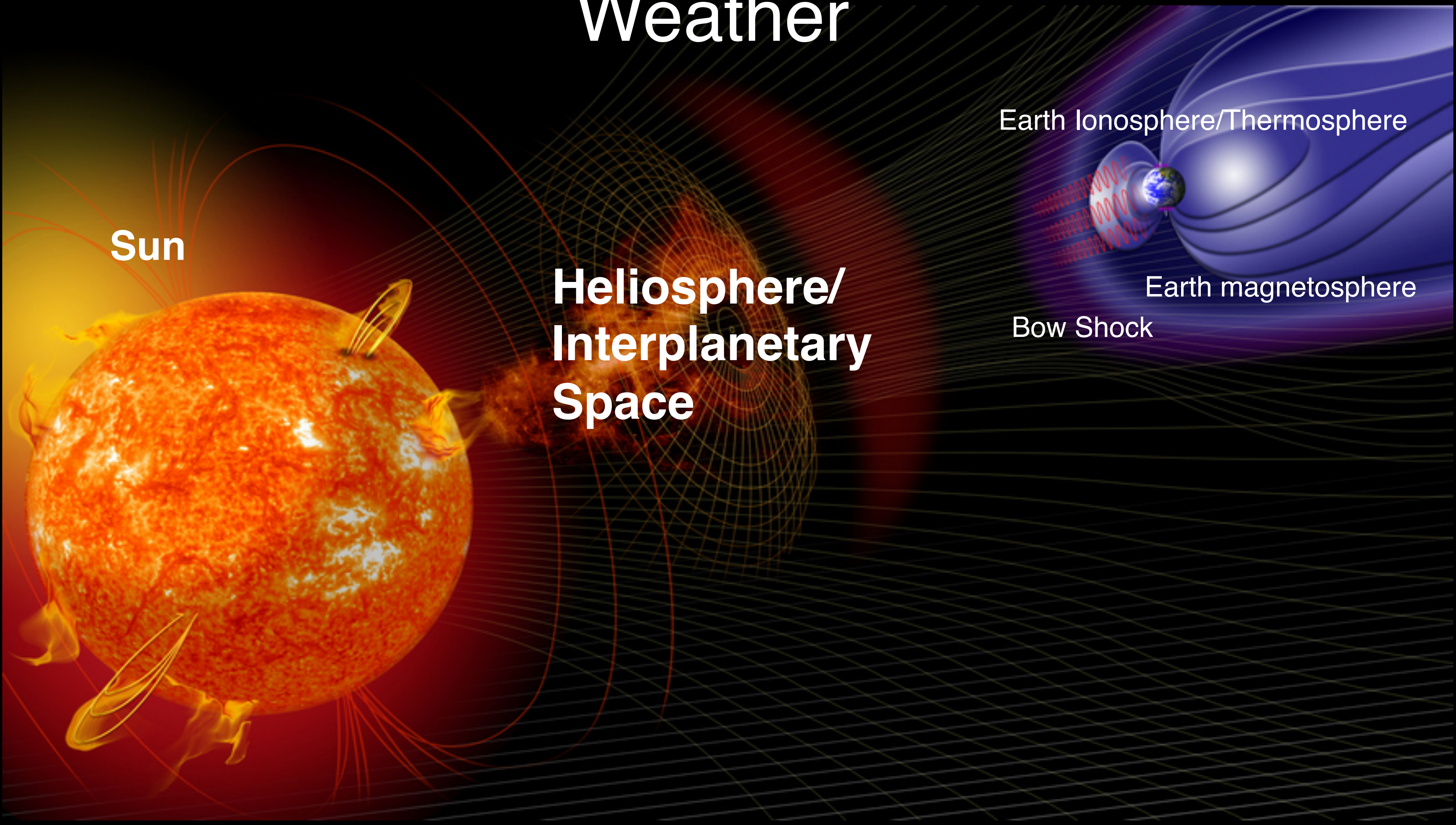
Physical Domains

*Heliosphere

Planets are mostly located in one plane
– called *ecliptic plane*

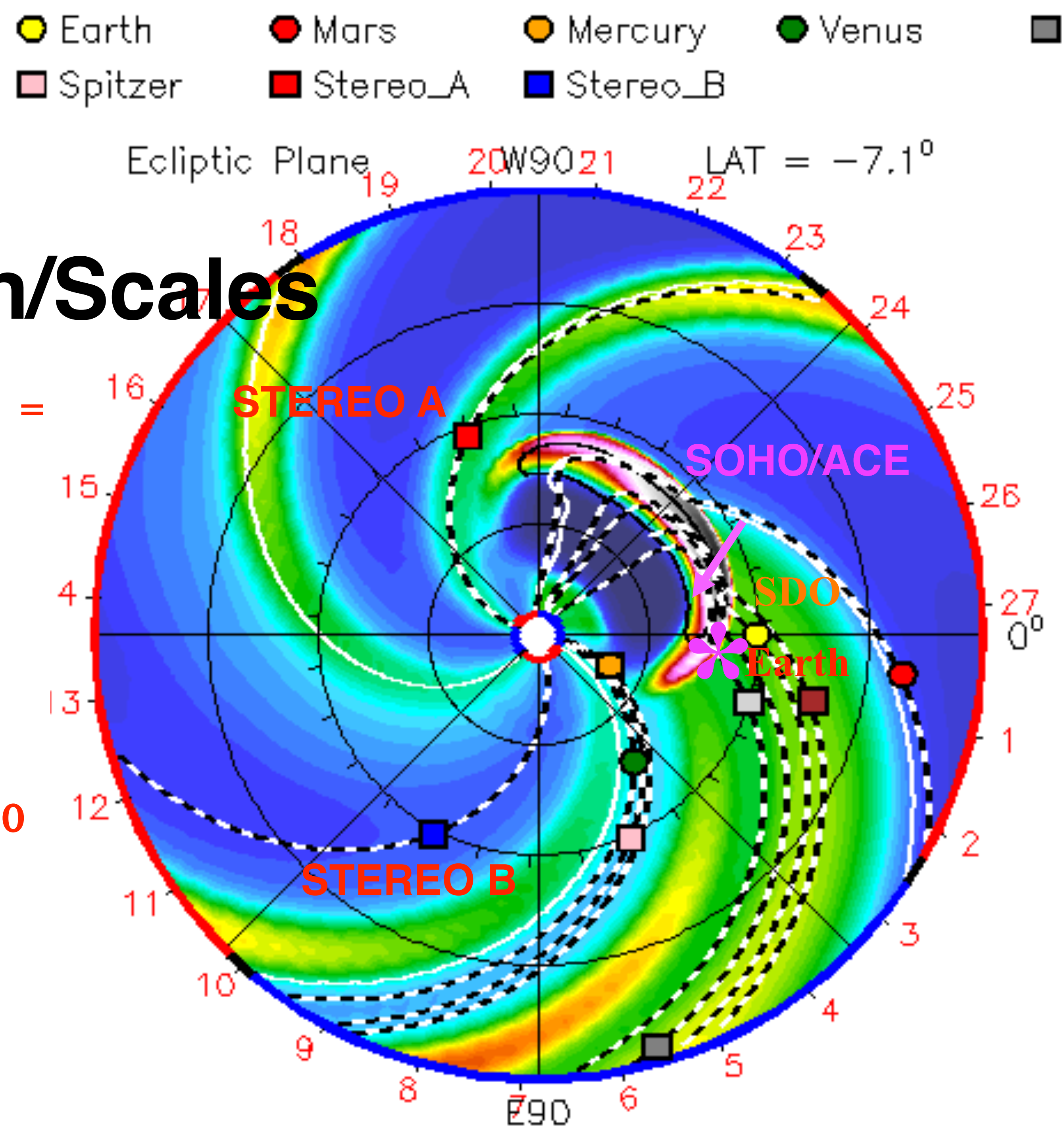


Different regions of Space Weather



Orientation/Scales

1AU = 150 million km = 93 million miles
1 Rs = 695,500 km = 110 RE
1 RE = 6371 km
MESSENGER: 0.3 AU
1 Sun can fill a little more than 1 million Earth
ACE/SOHO at L1: 1/100 of the Sun-Earth distance



A movie on space weather

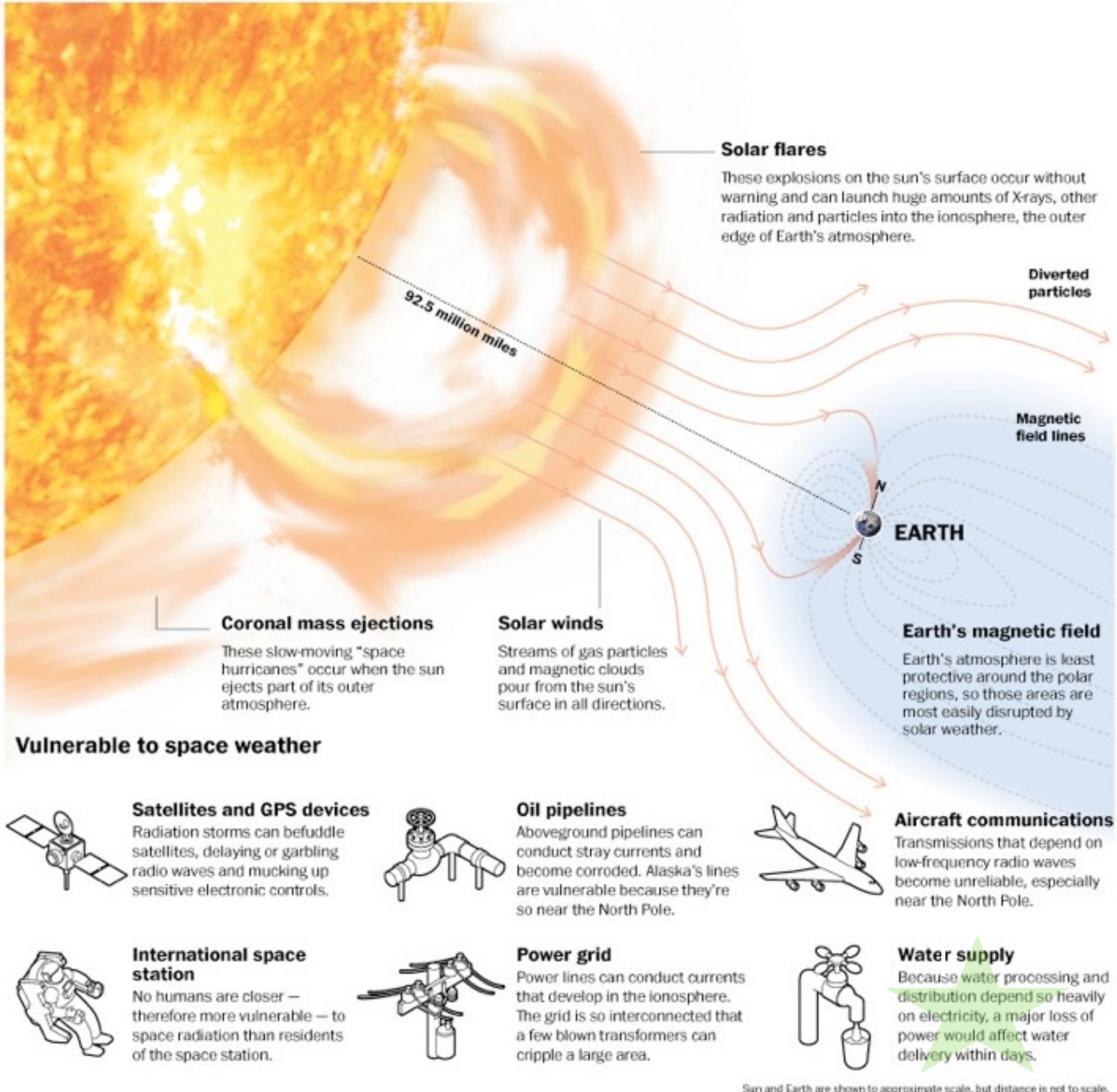
- http://missionscience.nasa.gov/sun/sunVideo_01spaceweather.html

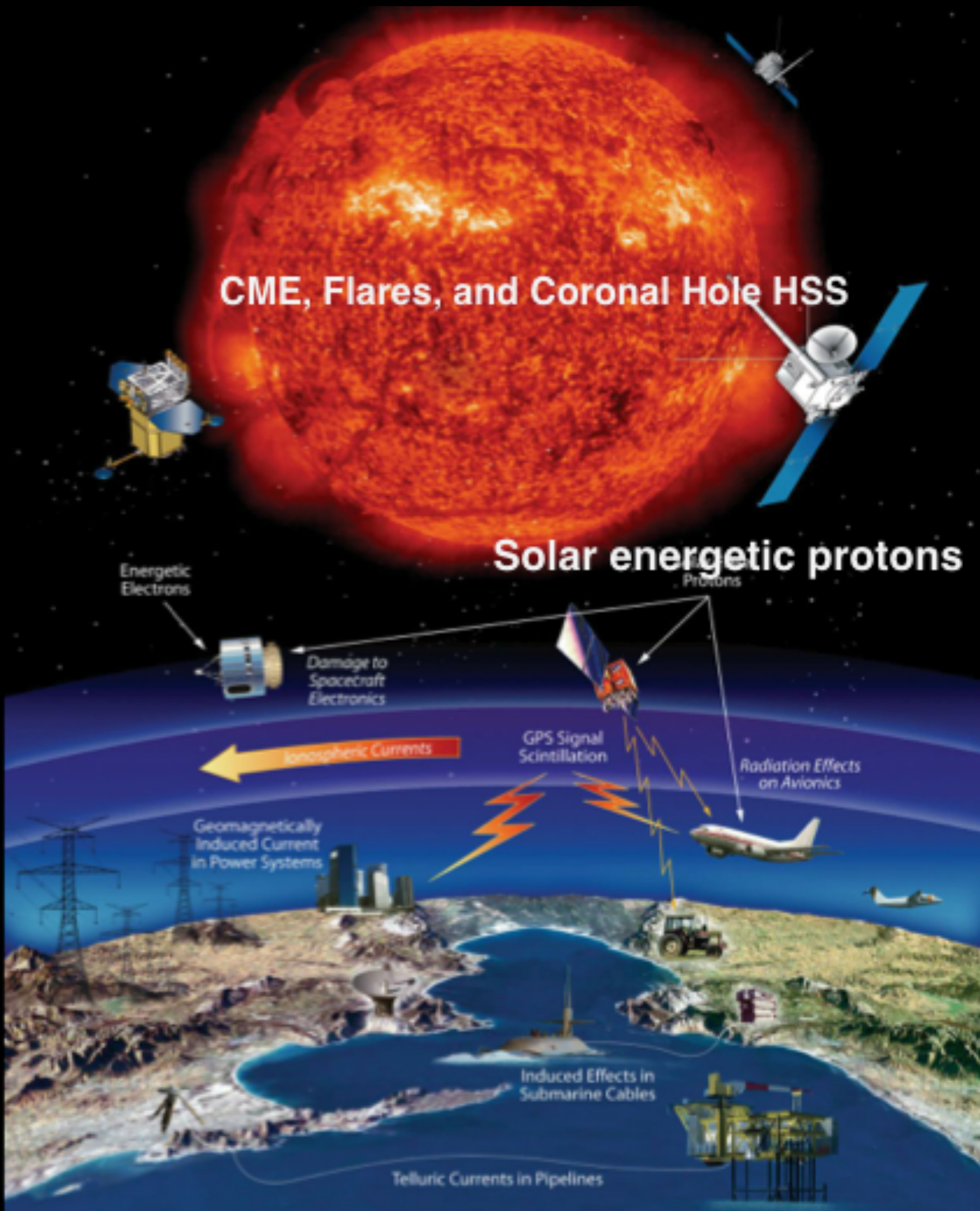
- A movie on space weather

Space Weather Vocabulary

Why do we care?

Space Weather Illustrated





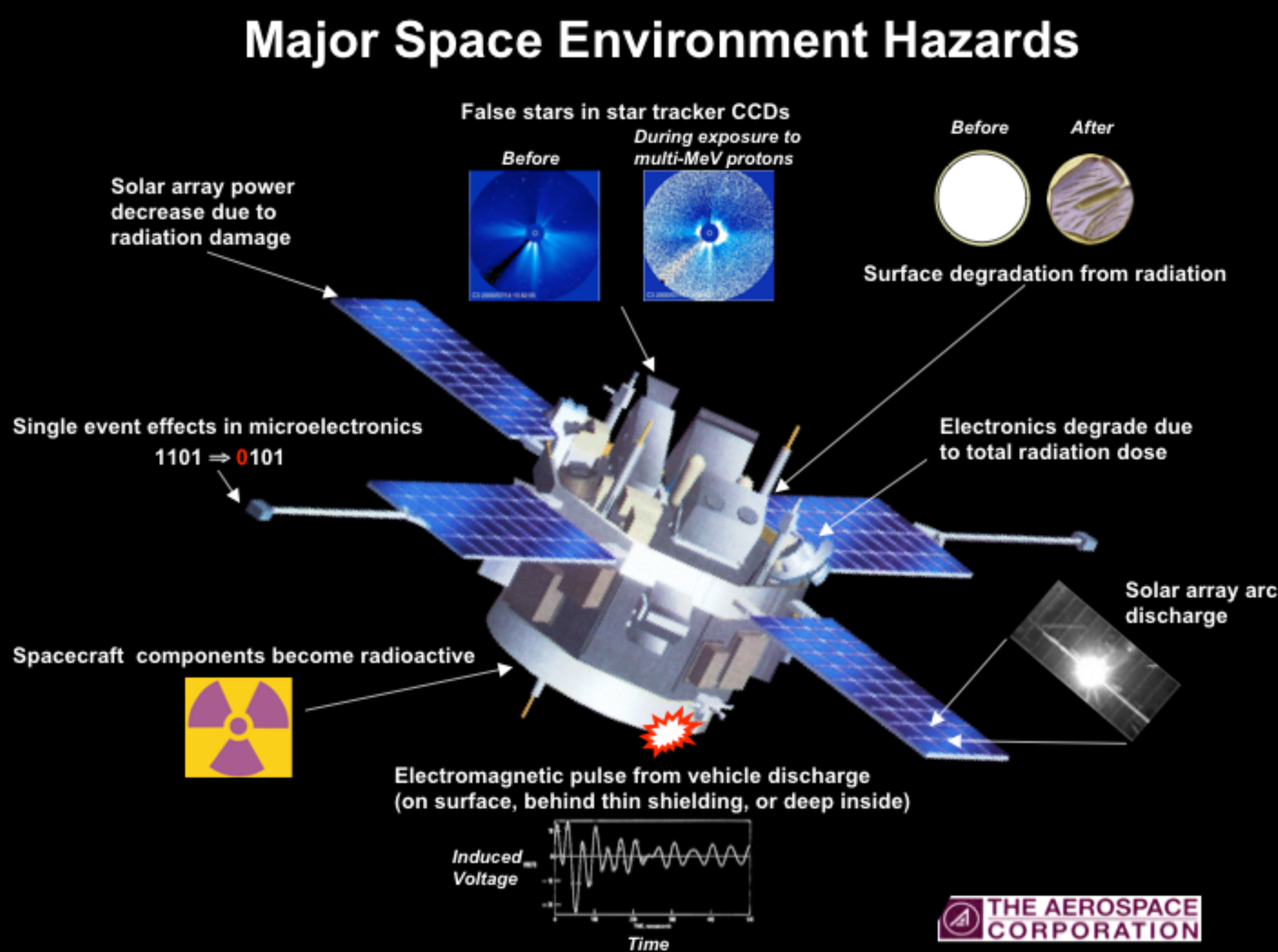
The Sun
maker of space weather

CME, Flares, and Coronal Hole HSS

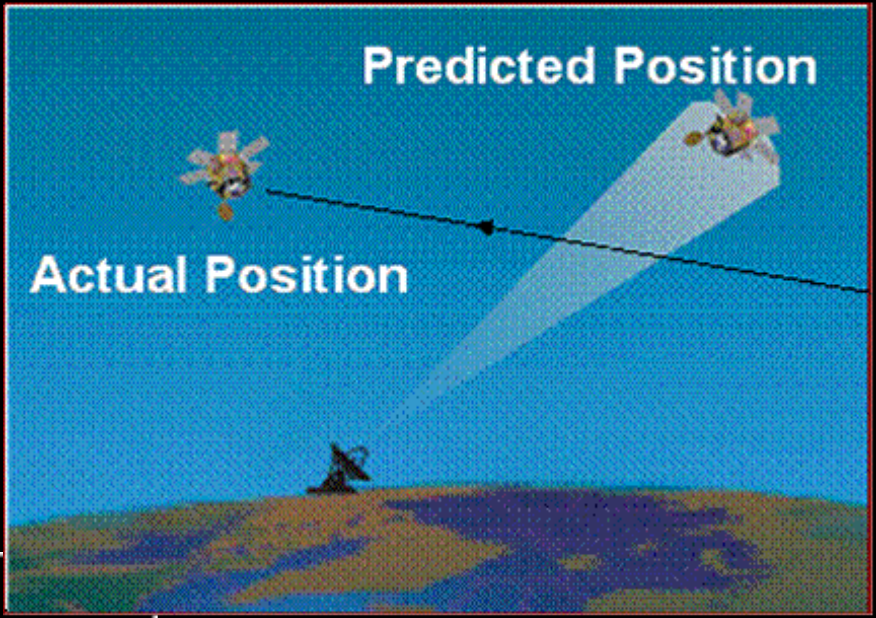
Three very important solar wind disturbances/structures for space weather

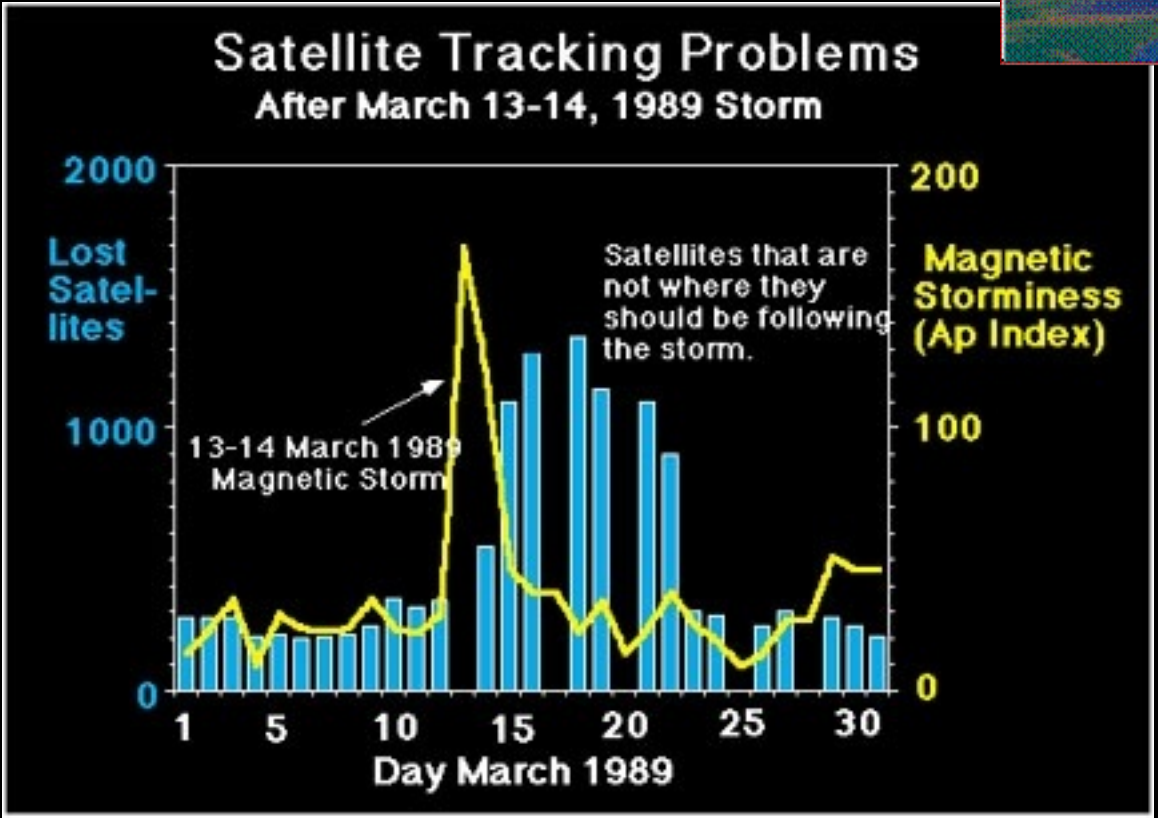
- **Radiation storm**
- **proton/ion radiation (SEP) <flare/CME>**
- **electron radiation <CIR HSS/ CME>**
- **Radio blackout storm <flare>**
- **Geomagnetic storm**
- **CME storm (can be severe)**
- **CIR storm (moderate)**

SWx impacts on spacecraft components



SWx impacts on satellite tracking



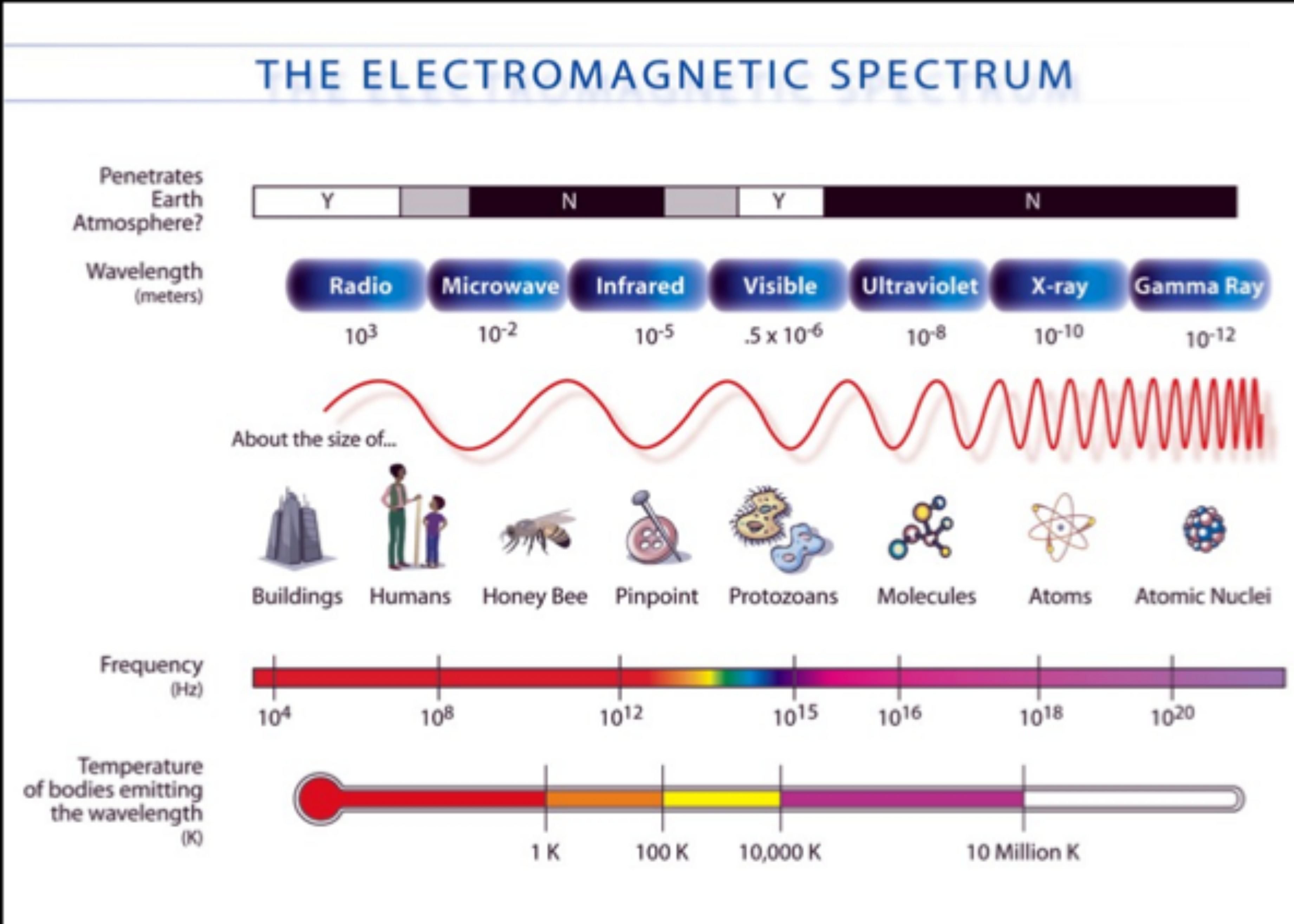


Main Drivers of Space weather: Flares/CMEs/ high speed solar wind streams

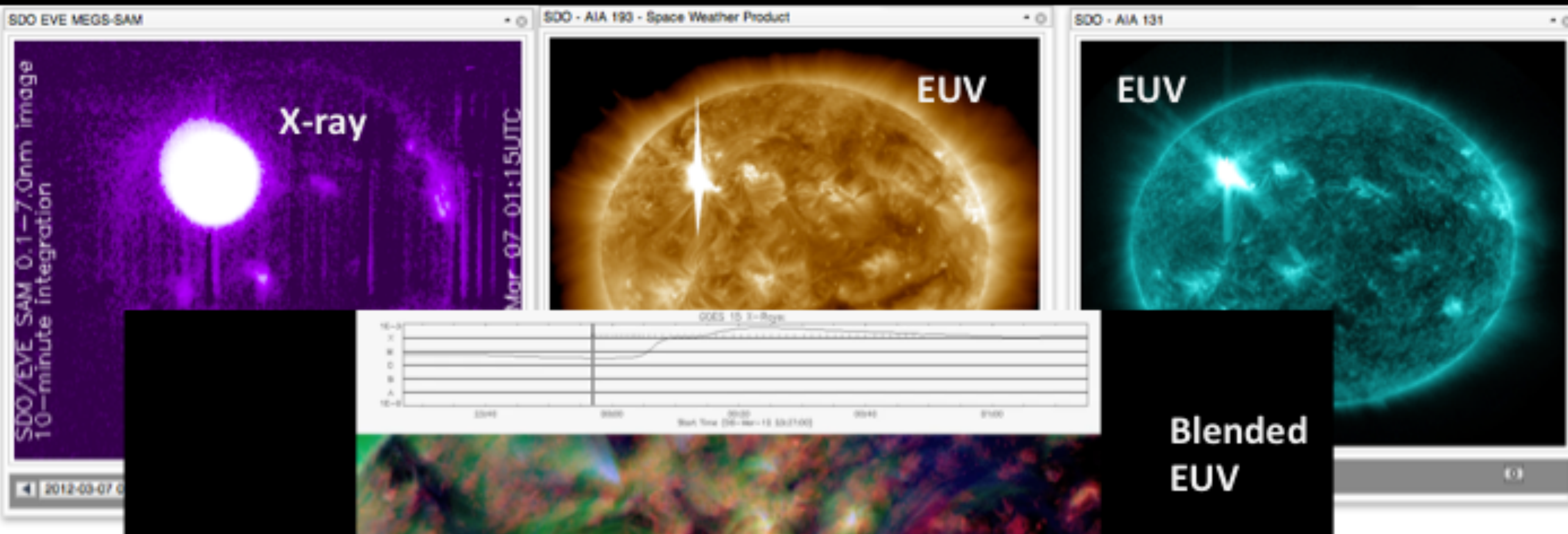
Solar Flares

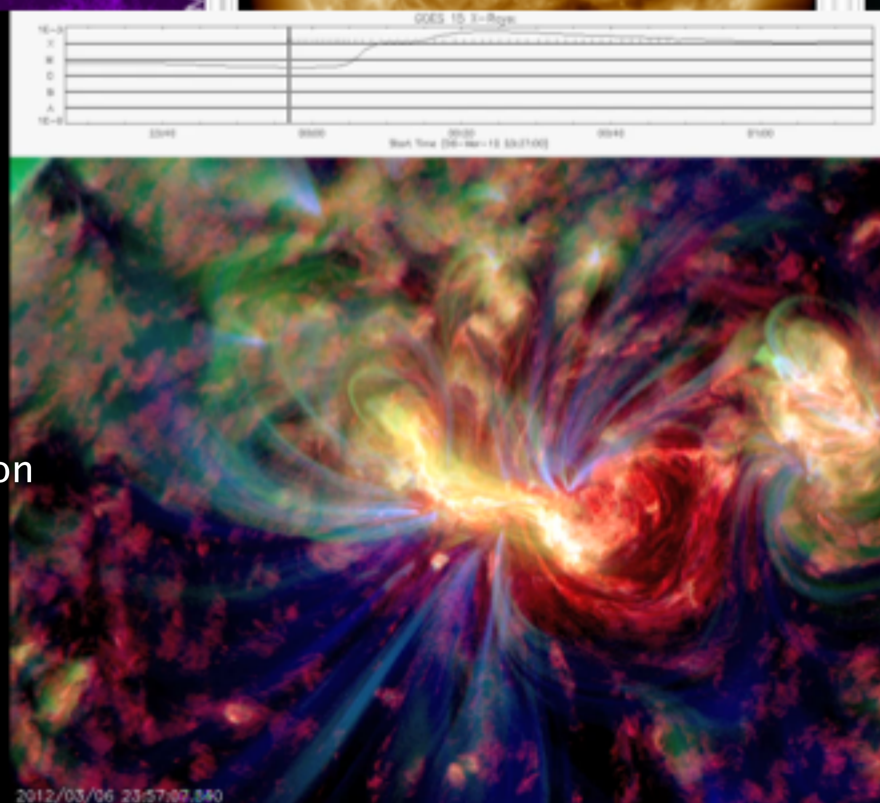
radiation across the electromagnetic spectrum

most pronounced in EUV and soft X-ray


THE ELECTROMAGNETIC SPECTRUM
Penetrates Earth Atmosphere?
Y
N
Y
N
Wavelength (meters)
Radio
Microwave
Infrared
Visible
Ultraviolet
X-ray
Gamma Ray
10^{3}
10^{-2}
10^{-5}
$.5 \times 10^{-6}$
10^{-8}
10^{-10}
10^{-12}
About the size of...
Buildings
Humans
Honey Bee
Pinpoint
Protozoans
Molecules
Atoms
Atomic Nuclei
Frequency (Hz)
10^{4}
10^{8}
10^{12}
10^{15}
10^{16}
10^{18}
10^{20}
Temperature of bodies emitting the wavelength (K)
1 K
100 K
10,000 K
10 Million K

2012 March 7 X5.4/X1.3 Flares





Blended EUV

Solar Flare:
sudden brightening on the sun's surface

Flares radiate throughout the electromagnetic spectrum

Most pronounced in x-ray and EUV

Flare: SWx impacts

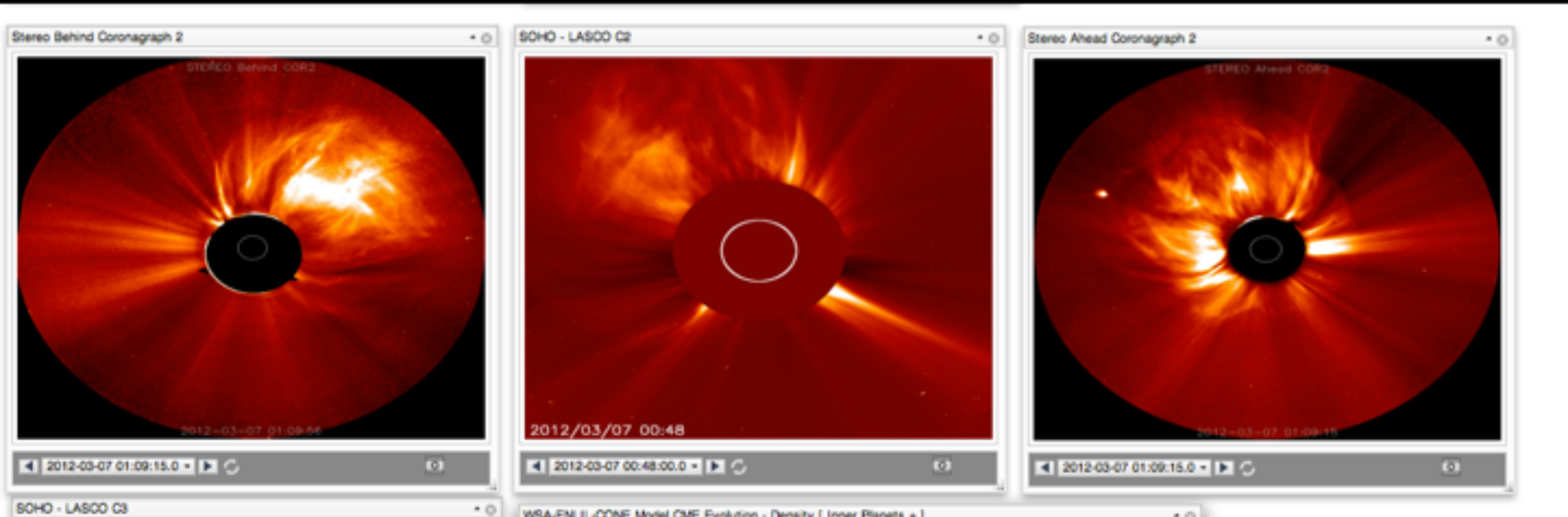
- Cause radio blackout through changing the structures/composition of the ionosphere (sudden ionospheric disturbances) – x ray and EUV emissions, lasting minutes to hours and dayside
- Affect radio comm., GPS, directly by its radio noises at different wavelengths
- Contribute to SEP – proton radiation, lasting a couple of days

Coronal Mass Ejections (CMEs)

CME

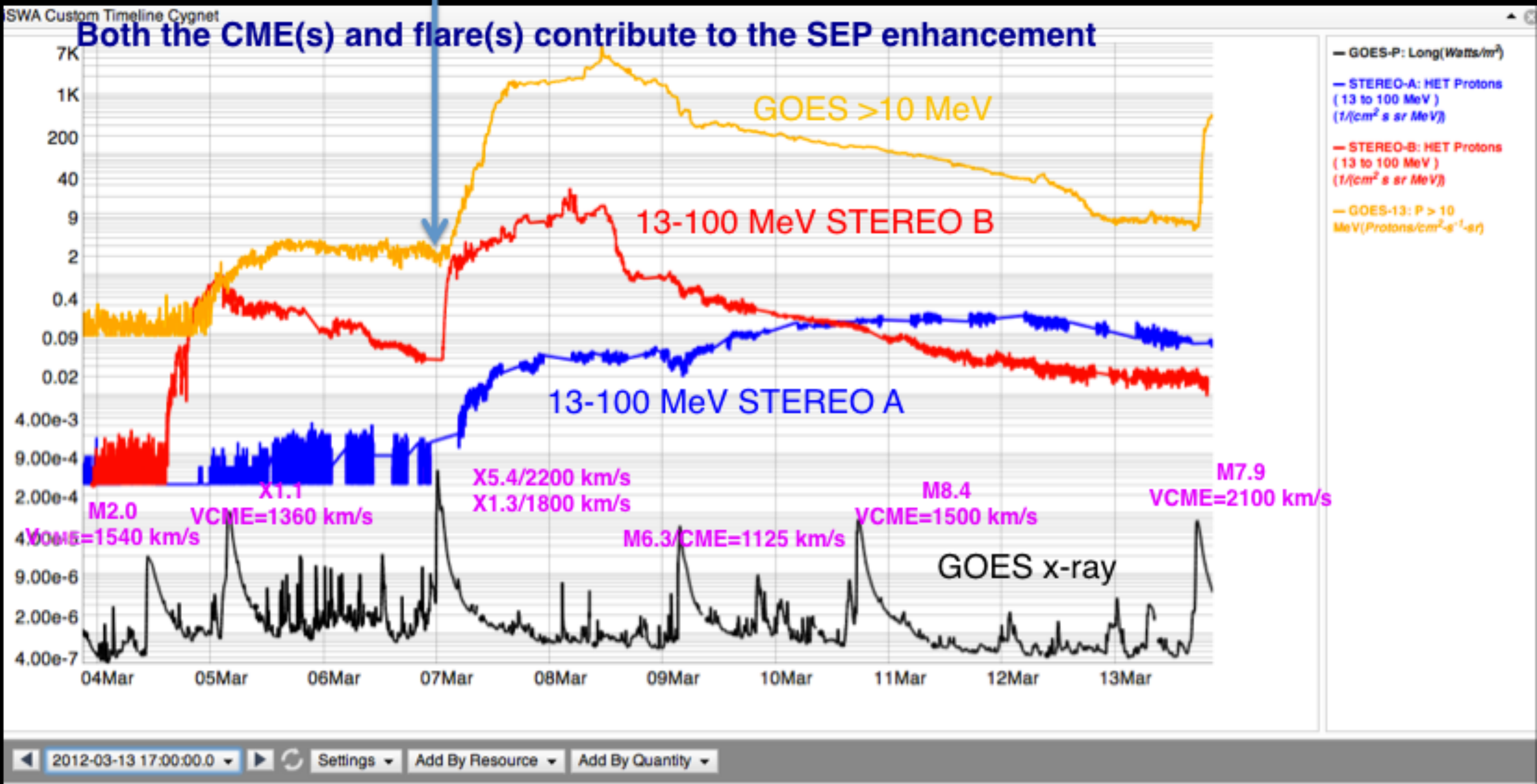
- Massive burst of solar materials and magnetic field/flux into the interplanetary space: 10^15 g
- Kinetic energy 10^32 erg
- Yashiro et al. (2006) find that virtually all X-class flares have accompanying CMEs

CME viewed by coronagraph imagers



- Eclipses allow corona to be better viewed
    - Does not happen often
- Modern coronagraph imager is inspired by that: Occulting disk blocks the bright sun so we can observe corona features better

SEP: proton radiation

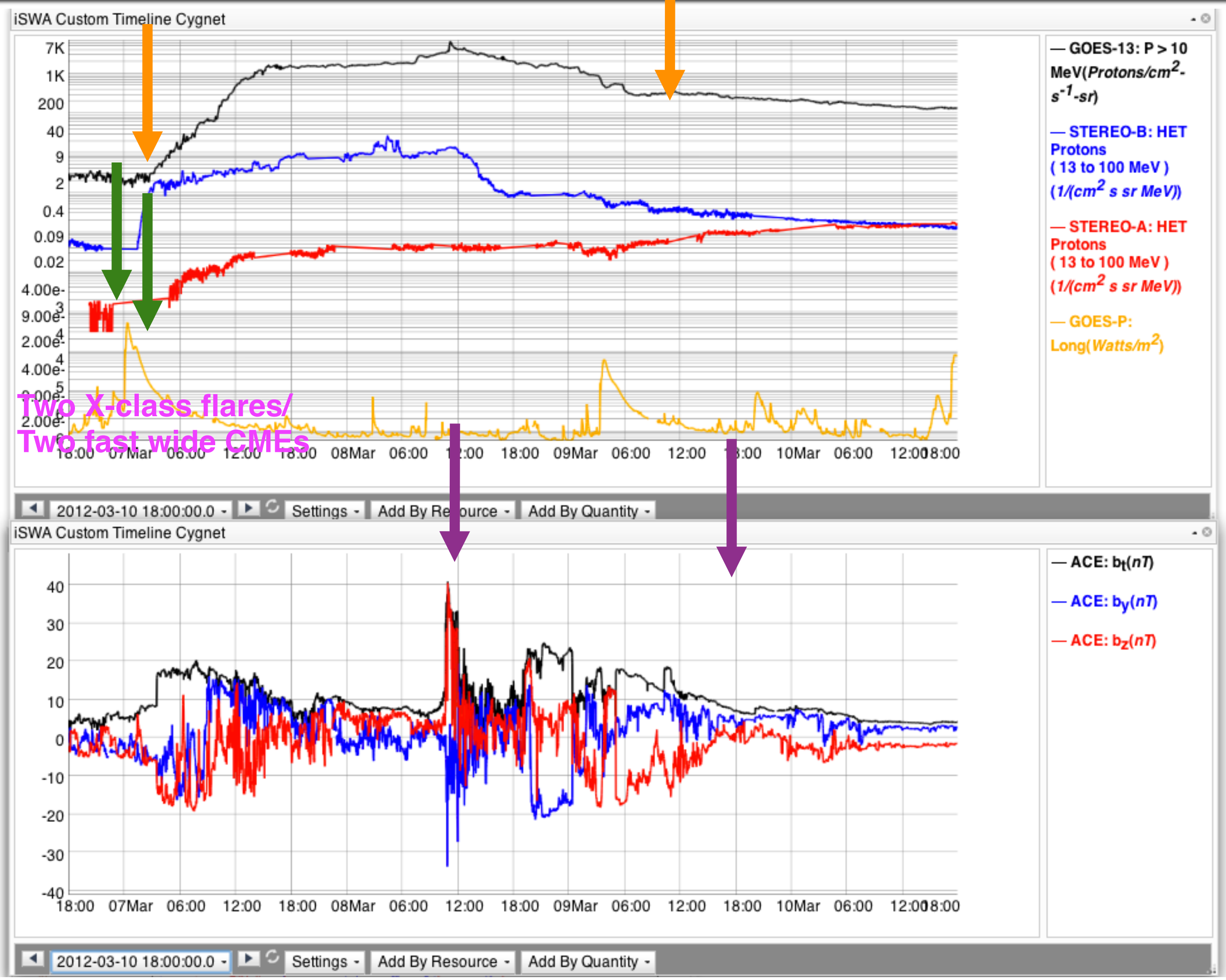


SWx Impacts of a CME

- Contribute to SEP (proton/ion radiation): 20-30 minutes from the occurrence of the CME/flare
- Result in a geomagnetic storm: takes 1-2 days arriving at Earth
- Result in electron radiation enhancement in the near-Earth space (multiple CMEs): takes 1-3 days
- Affecting spacecraft electronics – surfacing charging/internal charging, single event upsets (via SEPs)
- Radio communication, navigation
- Power grid, pipelines, and so on

Space Weather Effects and Timeline

(Flare and CME)



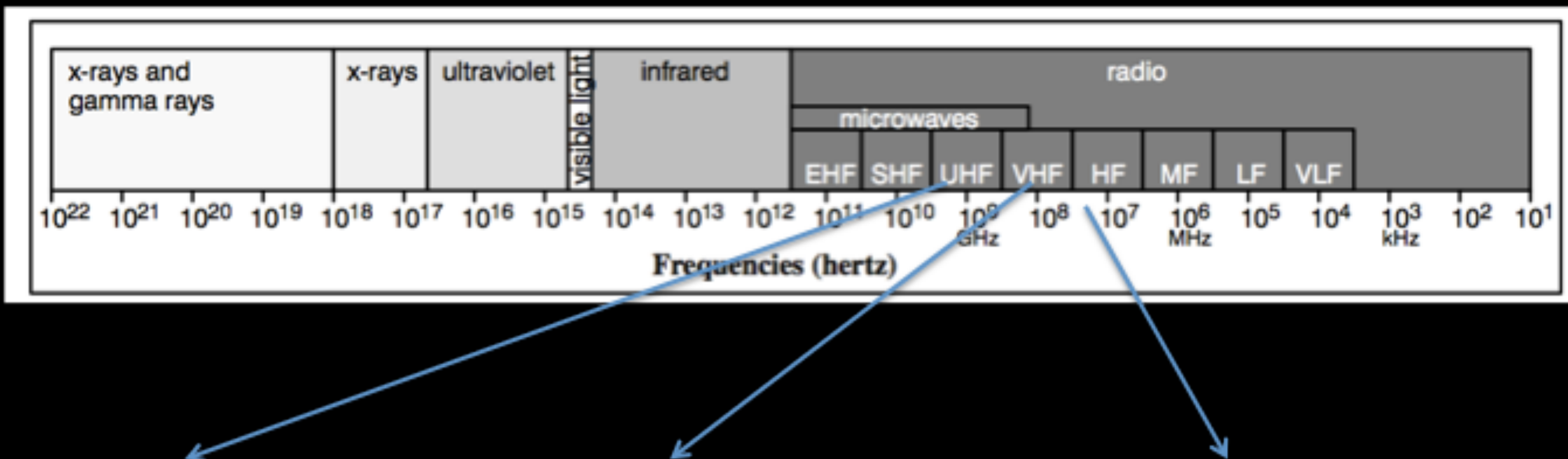
Flare effects at Earth:
~ 8 minutes (radio blackout storms)
Duration: minutes to hours

SEP radiation effects reaching Earth: 20 minutes – 1hour after the event onset
Duration: a few days

CME effects arrives @ Earth: 1-2 days (35 hours here)
Geomagnetic storms: a couple of days

Extras

Types of space weather events affecting nav and commu



UHF – GPS

- Energetic protons/ particles – via SEEs - affecting GPS satellites components
- Geomagnetic storms/ ionospheric storm - cause scintillations

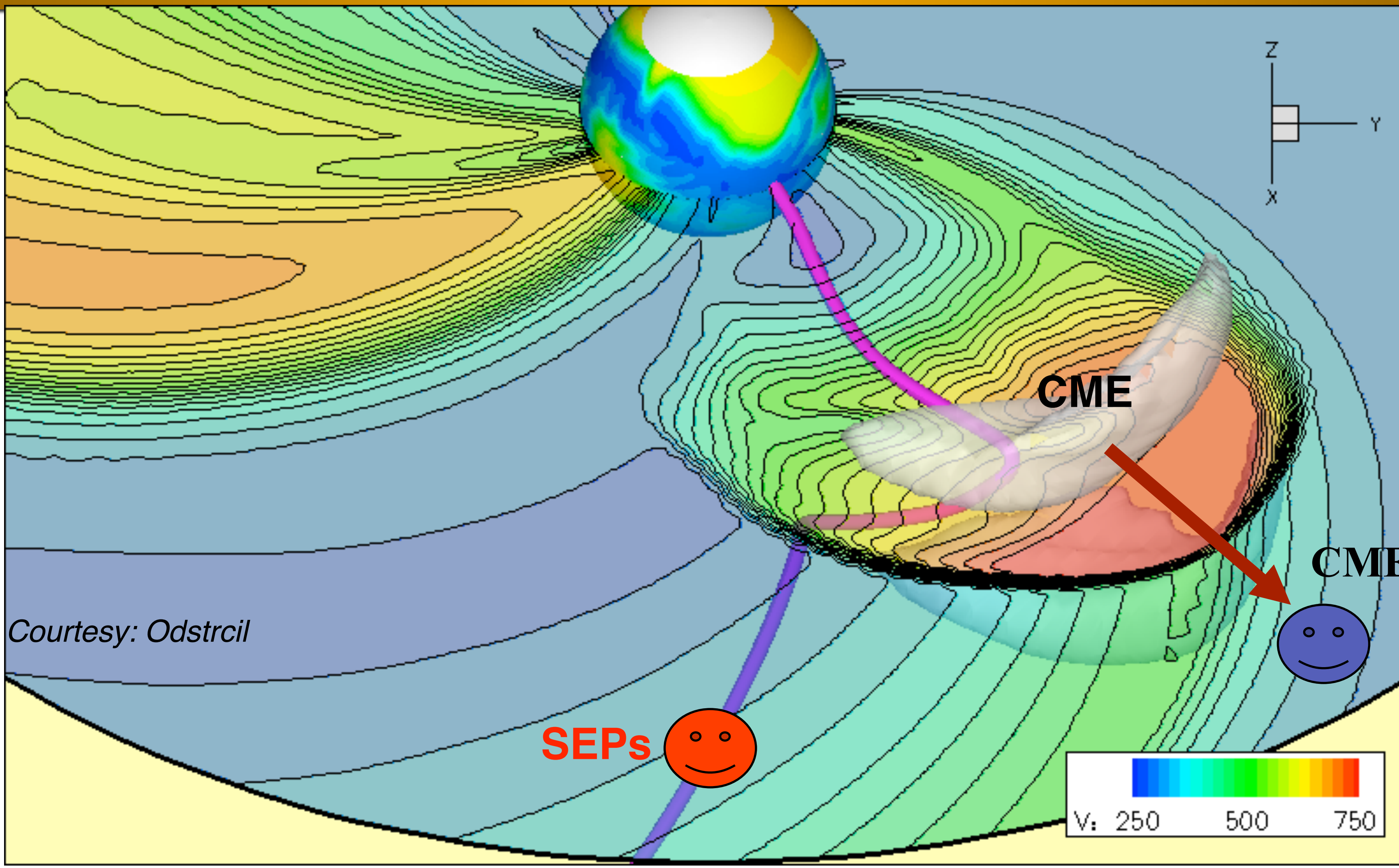
VHF:

- Energetic protons - PCA
- Geomagnetic storms
- Solar radio emission associated with flare/CME

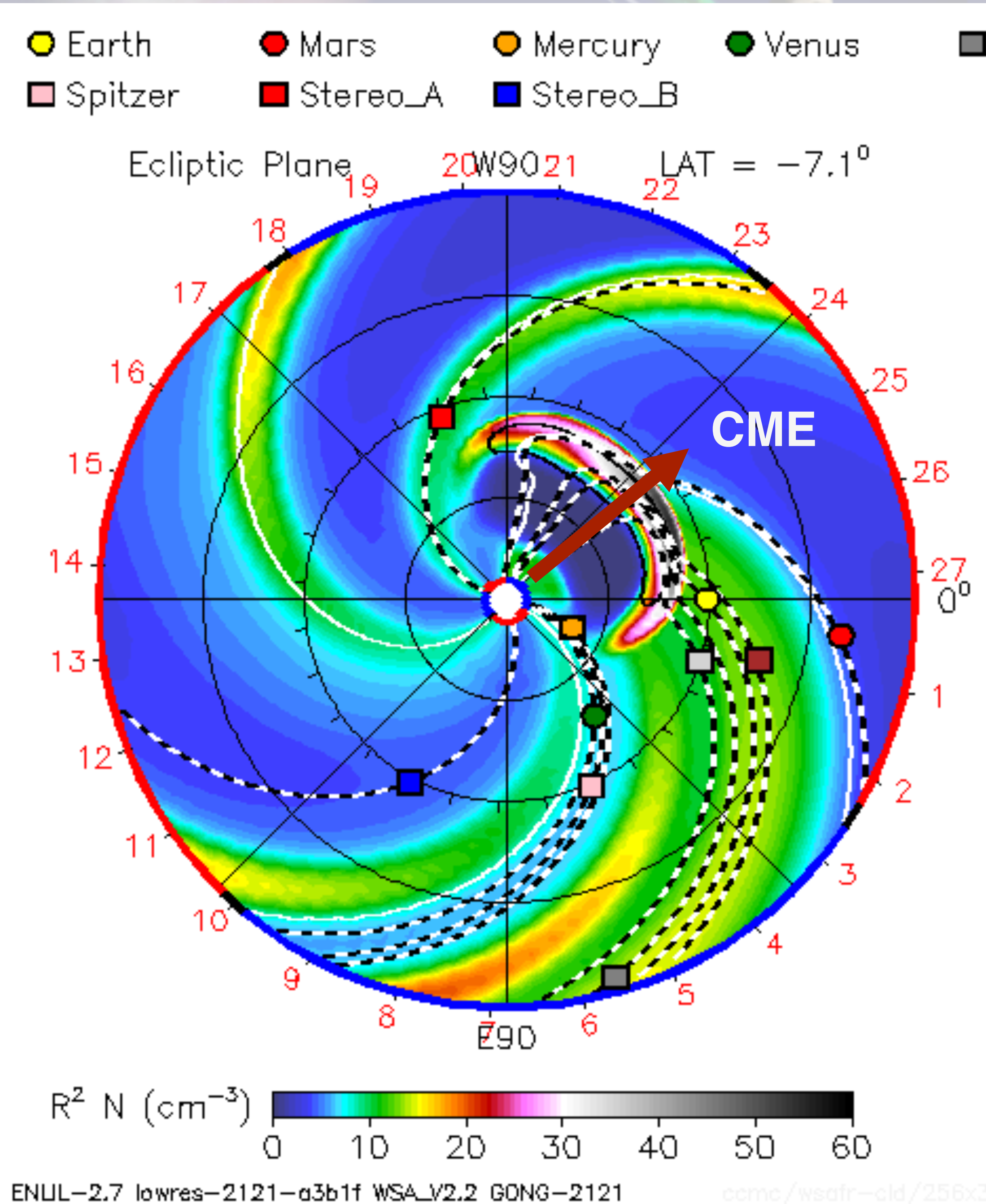
HF:

- Solar flares/x-ray
- Energetic protons - PCA
- Geomagnetic activities

CME and SEP path are different



CME: could get deflected, bended, but more or less in the radial direction



Important distinction

Ion Radiation storm vs Geomagnetic storm

CME impact and SEP (Solar Energetic Particle) impact are different

CME impact @ Earth: Geomagnetic Storm

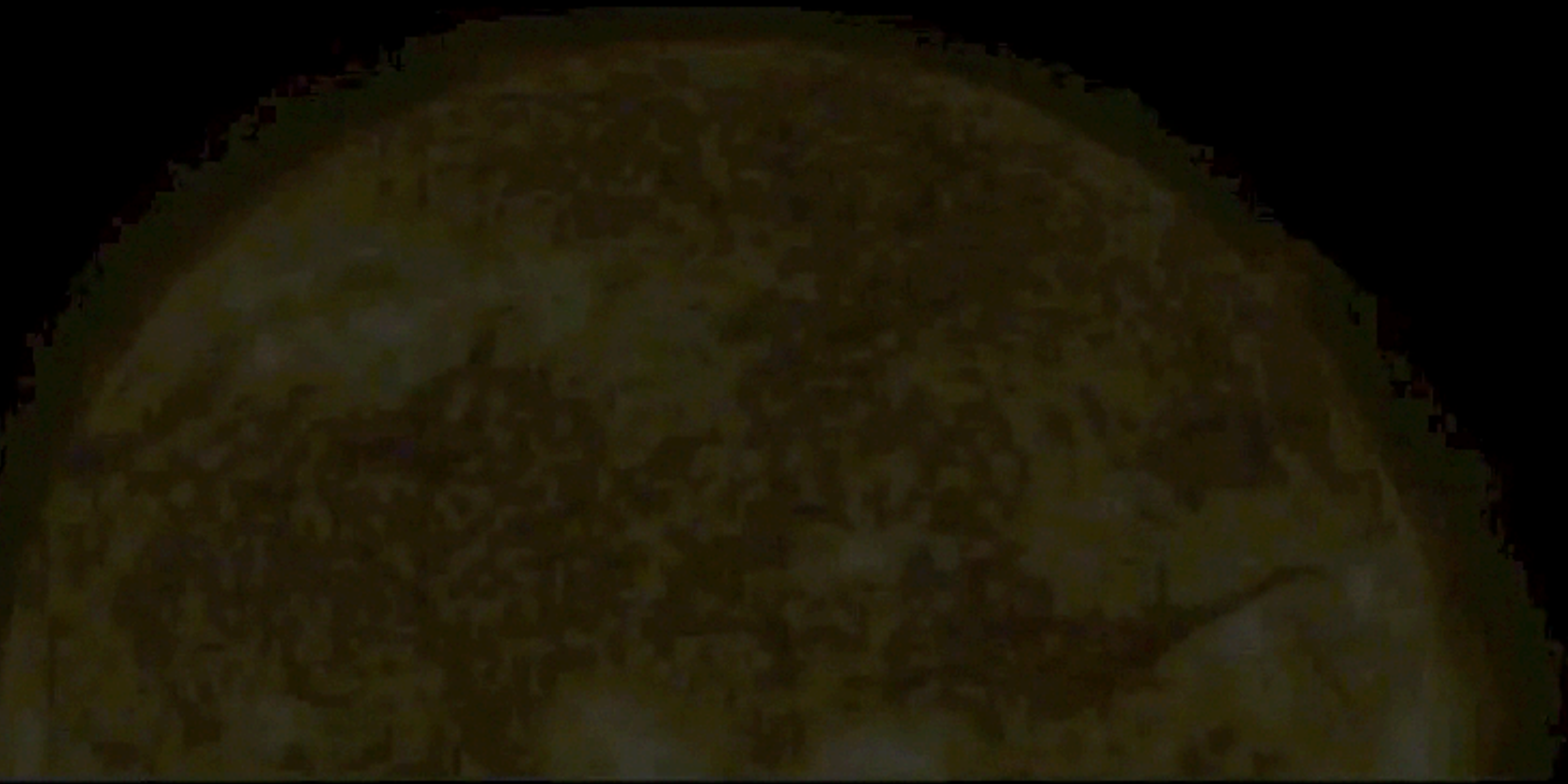
Radiation storm @ Earth from SEPs

CME speed: 300 – 3500 km/s
SEPs: fraction of c
Light speed c: 3 x10^5 km/s

SEPs: ion radiation storms

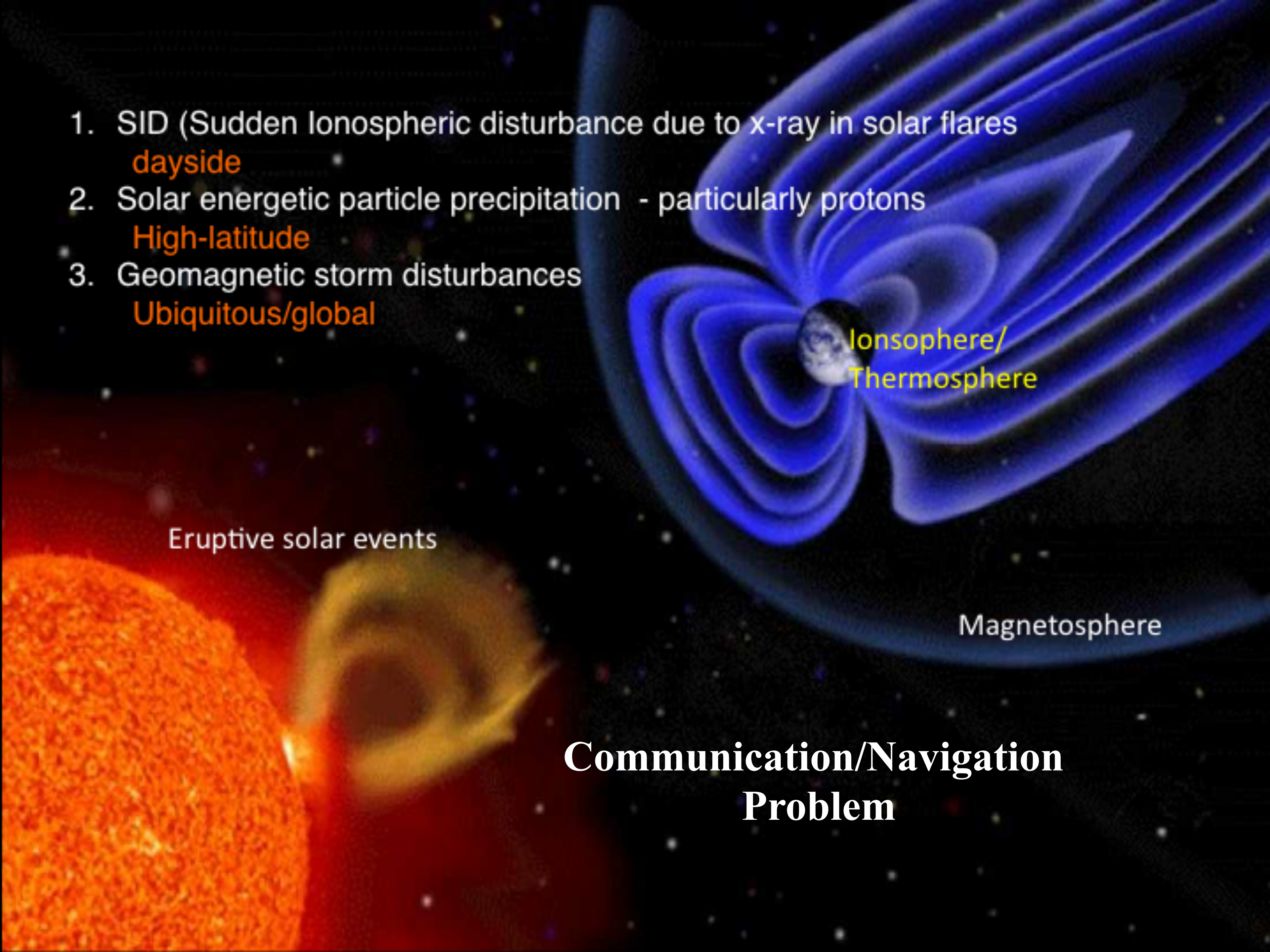
Potentially affect everywhere in the solar system

illustration of Geomagnetic storms due to a CME



Geomagnetic storms due to CIRs are at most moderate

1. SID (Sudden Ionospheric disturbance due to x-ray in solar flares
   dayside
2. Solar energetic particle precipitation - particularly protons
   High-latitude
3. Geomagnetic storm disturbances
   Ubiquitous/global



Communication/Navigation Problem

Solar radio bursts can directly affect GPS operation

- Solar radio bursts during December 2006 were sufficiently intense to be measurable with GPS receivers. The strongest event occurred on 6 December 2006 and affected the operation of many GPS receivers. This event exceeded 1,000,000 solar flux unit and was about 10 times larger than any previously reported event. The strength of the event was especially *surprising* since the solar radio bursts occurred near solar minimum. The strongest periods of solar radio burst activity lasted a few minutes to a few tens of minutes and, in some cases, exhibited large intensity differences between L1 (1575.42 MHz) and L2 (1227.60 MHz). Civilian dual frequency GPS receivers were the most severely affected, and these events suggest that continuous, precise positioning services should account for solar radio bursts in their operational plans. This investigation raises the possibility of even more intense solar radio bursts during the next solar maximum that will significantly impact the operation of GPS receivers.

Cerruti et al., 2008, Space Weather

Ionosphere Irregularities

- plasma bubbles: typical east–west dimensions of several hundred kilometers contain irregularities with scale-lengths ranging from tens of kilometers to tens of centimeters (Woodman and Tsunoda). Basu et al. (1978) showed that between sunset and midnight, 3-m scale irregularities that cause radar backscatter at 50 MHz, co-exist with sub-kilometer scale irregularities that cause VHF and L-band scintillations. After midnight, however, the radar backscatter and L-band scintillations decay but VHF scintillations caused by km-scale irregularities persist for several hours.

Journal of Atmospheric and Solar-Terrestrial Physics Volume 61, Issue 16, 1 November 1999, Pages 1219-1226